Late Ordovician Allochthonous Limestones in Late Silurian Barnby Hills Shale, Central Western New South Wales

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Allochthonous limestone blocks exposed in the Eurimbla area, west of the Mitchell Highway between Molong and Wellington, are substantially older than the enclosing Barnby Hills Shale of Late Silurian age. Nine of the blocks yielded a diverse Late Ordovician conodont fauna, dominated by *Panderodus gracilis*, *Belodina confluens*, *Periodon grandis*, *Paroistodus*? *nowlani* and *Yaoxianognathus*? *tunguskaensis*. Occurrence of *Taoqupognathus blandus* in seven sampled blocks indicates an early Eastonian (Ea2) age, although rare *Taoqupognathus tumidus* in one suggests an extension into the late Eastonian (Ea3). These age determinations are confirmed by the presence of a silicified brachiopod fauna with typical elements (predominantly *Mabella halis* and *Doleroides mixticius*) of the previously defined fauna B of Eastonian 2 age. The conodont and articulate brachiopod faunas from the Eurimbla blocks are comparable with those from autochthonous limestones of Eastonian age elsewhere in the Molong Volcanic Belt, in particular the Bowan Park Group, except for occurrence of the conodont *Webbygnathus munusculum* and brachiopod *Sowerbyella billabongensis* which, in the Lachlan Orogen, are otherwise known only from the Junee-Narromine Volcanic Belt to the west. The allochthonous blocks may have been subject to one or more episodes of erosion and redeposition, prior to final emplacement in the Barnby Hills Shale.

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KEYWORDS: allochthonous limestones, Barnby Hills Shale, brachiopods, conodonts, Late Ordovician, Late Silurian.

INTRODUCTION

Regional mapping recently conducted by the Geological Survey of New South Wales in the central Lachlan Orogen has revealed that allochthonous limestones within the Late Silurian Barnby Hills Shale were derived from two major sources with substantial age differences. Morgan (1999: 92) determined that the Narragal Limestone, of early to middle Ludlow age (Percival 1998), provided the source of the Late Silurian limestone blocks and calcareous debris within the Barnby Hills Shale, based on faunal similarities and regional contact relationships. However, this is only the case within the belt of Barnby Hills Shale situated east of the Mitchell Highway (Fig. 1), for which Meakin and Morgan (1999) provided an extensive list of fossils from both the Silurian limestone blocks and the enclosing siliceous sediments.

Other allochthonous limestones emplaced within the Barnby Hills Shale in the Eurimbla district, west of the Mitchell Highway between Molong and Wellington, were first recognised as Late Ordovician in age by Webby (1969) who identified in them the stromatoporoids *Ecclimadictyon amzassensis* and *E. nestori*, indicative of his early Eastonian coral-stromatoporoid Fauna II. Locations of the larger of these blocks were shown on a regional map by Byrnes (*in* Pickett 1982; reprinted *in* Lishmund et al. 1986), but only relatively recently (Farrell *in* Talent 1995) was detailed mapping of the area undertaken. Percival, Engelbretsen and Brock (1999) noted the occurrence and Eastonian age of a diverse lingulate brachiopod fauna (12 species) from one of the blocks; systematic description of this fauna is underway. Documentation herein of the remainder of the fauna, including

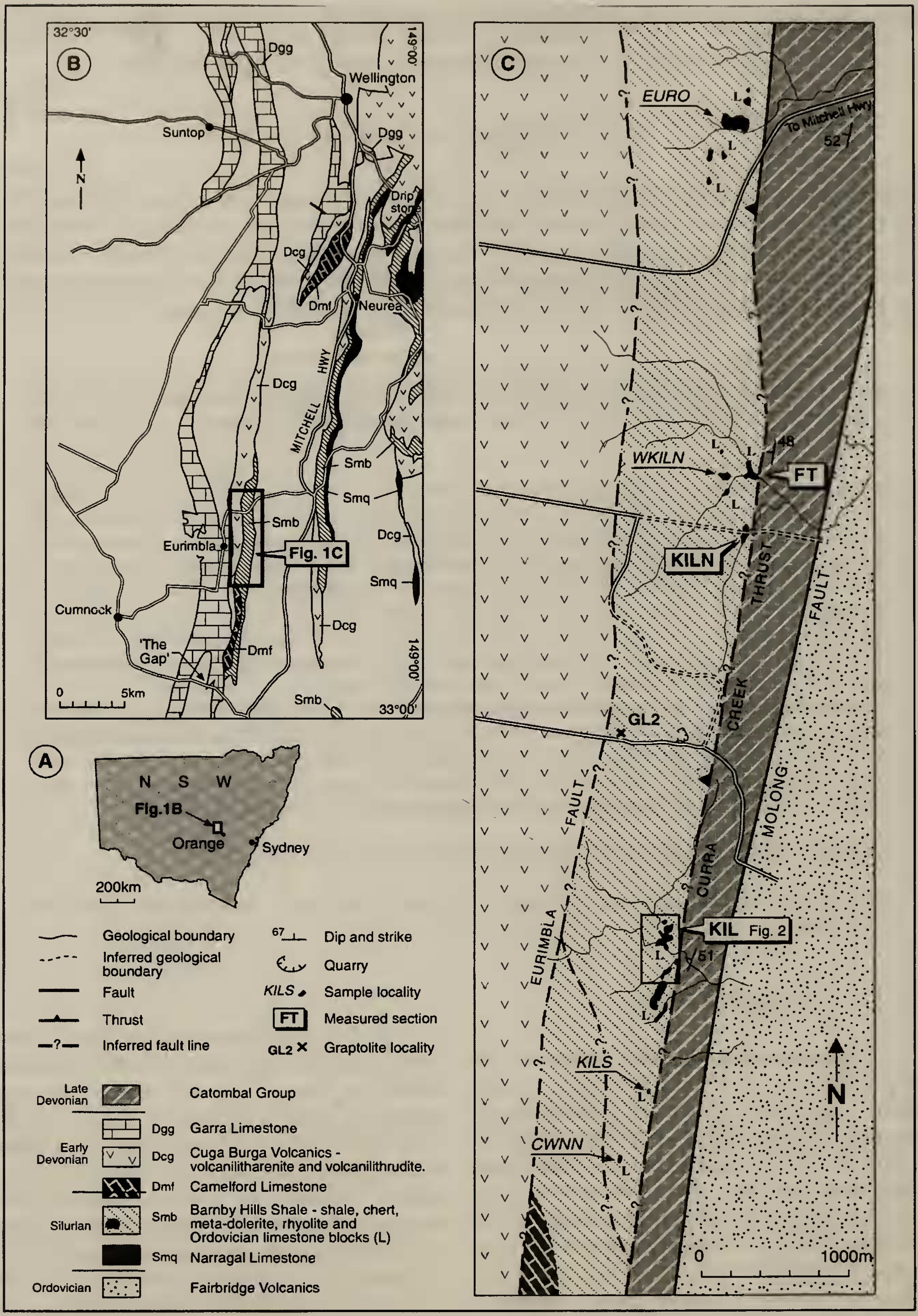

Figure 1. Locality maps. A. New South Wales showing location of figure 1B; B. simplified geological map of the area between Wellington and Cumnock, central New South Wales, showing position of figure 1C; C. geological map of the area to the east of Eurimbla, showing locations of sampled limestone blocks within the Barnby Hills Shale. Position of Figure 2, 'KIL' blocks, is also indicated.

conodonts and articulate brachiopods, provides confirmation of the Eastonian age of this suite of allochthonous blocks, and further enables informed speculation as to their origin.

GEOLOGICAL SETTING

The Barnby Hills Shale was initially proposed by Strusz (1960) for shales, siltstones and a few small limestone lenses comprising the upper member of the Mumbil Formation. He also identified *Monograptus bohemicus* in a siliceous siltstone bed within the unit, supporting a mid to late Ludlow age. The unit was subsequently raised to formation status by Vandyke and Byrnes (1976). Byrnes (*in* Pickett 1982: 146) regarded the section near the old "Mumbil" homestead, which was originally investigated by Strusz (1960), as the type section. However, due to faulting at the top and some internal folding at this locality, Morgan (1999: 90, photo 19 and fig. 21) more recently nominated the section exposed along a railway cutting on "Narrellen" property near Dripstone as the type section. At this locality, the formation is estimated to be 290 m thick, but it reaches a maximum thickness (over 700 m) in the Eurimbla area.

Strusz (1960) stated that the Barnby Hills Shale was in conformable contact with the Early Devonian Cuga Burga Volcanics, but Chatterton et al. (1979) showed that the Camelford Limestone was intercalated between these two units, and that it had a conformable contact with both the Cuga Burga Volcanics and the Barnby Hills Shale. At Neurea, the Barnby Hills Shale conformably overlies the Narragal Limestone, the upper layers of which have been dated, using conodont data, as mid Ludlow *siluricus* Zone (Percival 1998). Graptolites from the Barnby Hills Shale at Neurea include *Bohemograptus bohemicus tenuis* Boucek, *Pristiograptus dubius* cf. *frequens* Jaekel and *Egregiograptus egregius byrnesianum* Rickards and Wright, indicative of a late Ludlow age (Rickards and Wright 1997). Hence in this eastern belt of outcrop of the Barnby Hills Shale, the age of allochthonous limestone blocks derived from the Narragal Limestone (Morgan 1997, 1999) is only slightly older than that of the clastic sediments into which they were redeposited.

This is not the case, however, in the belt of Barnby Hills Shale situated west of the Mitchell Highway, and east of Eurimbla (Fig. 1). In the mapped area (Fig. 1B), the Barnby Hills Shale is fault-bounded, having over-ridden the Late Devonian Catombal Group to the east along the Curra Creek Thrust, and being bounded by the Cuga Burga Volcanics along the Eurimbla Fault to the west. Graptolites recovered from locality 'GL2' (GR 672700E 6352100N, Cumnock 1:50,000 8632-S), within the upper horizons of the siltstone sequence, have been identified as *Monograptus ludensis* (Murchison), indicating a latest Wenlock age (R.B. Rickards pers. comm.). From near the 'KIL' section at GR 673850E 6359110N, Sherwin (1997) reported the occurrence of *Monograptus* (*Saetograptus*) *colonus*, indicative of an early Ludlow age (*Neodiversograptus nilssoni* to early *Lobograptus scanicus* zones). North-east of 'The Gap' (Fig. 1), several graptolite species including *Bohemograptus praecornutus* Urbanek (*praecornutus* Biozone, ie middle Ludlow) were discovered in the uppermost horizons of the Barnby Hills Shale (R.B. Rickards pers. comm.). Given the evidence in this area of a latest Wenlock to mid Ludlow age for the upper part of the Barnby Hills Shale, that name is retained despite arguments (Talent and Mawson 1999; Cockle 1999) for its suppression in favour of the more restricted, in both location and depositional time frame, late Ludlow (and younger) Wallace Shale (Sherwin and Rickards 2002) – these two formations being demonstrably non-contemporaneous.

DISTRIBUTION OF ALLOCHTHONOUS LIMESTONES

Eighteen allochthonous limestone bodies of various sizes, ranging from less than a few metres to nearly 200 m in length, are emplaced at or near the faulted base of the Barnby Hills Shale, along the western side of the Curra Creek Thrust, and extend laterally for approximately 7 km on a NS trend (Fig. 2). The limestone outcrops occur in three major groupings. One group is situated in close proximity to the 'KIL' locality; another incorporates the outcrops at 'KILN', 'WKILN' and 'FT' localities, while the third is grouped around a large outcrop at 'EURO'. In addition, two very small isolated outcrops occur at 'CWNN' and 'KILS'.

The limestones are predominantly fine-grained and light to dark grey in colour with some isolated light fawn beds. Muddy intervals and rubbly beds are confined to a single block at the 'KIL' locality. Calcite veining is extensive at locality 'FT' and sets this outcrop at variance to all the others. Apart from a large syncline towards the top of block 'KIL-C', no other folding or faulting is apparent within the allochthonous blocks. Bedding is clearly evident in all blocks and varies from a few centimetres to 1 m in thickness. Apart from the silicified section in block 'KIL-B' (which yielded the abundant brachiopod fauna documented herein) and a coarsely silicified interval around sample number 78 in the same block, macro-fossils are

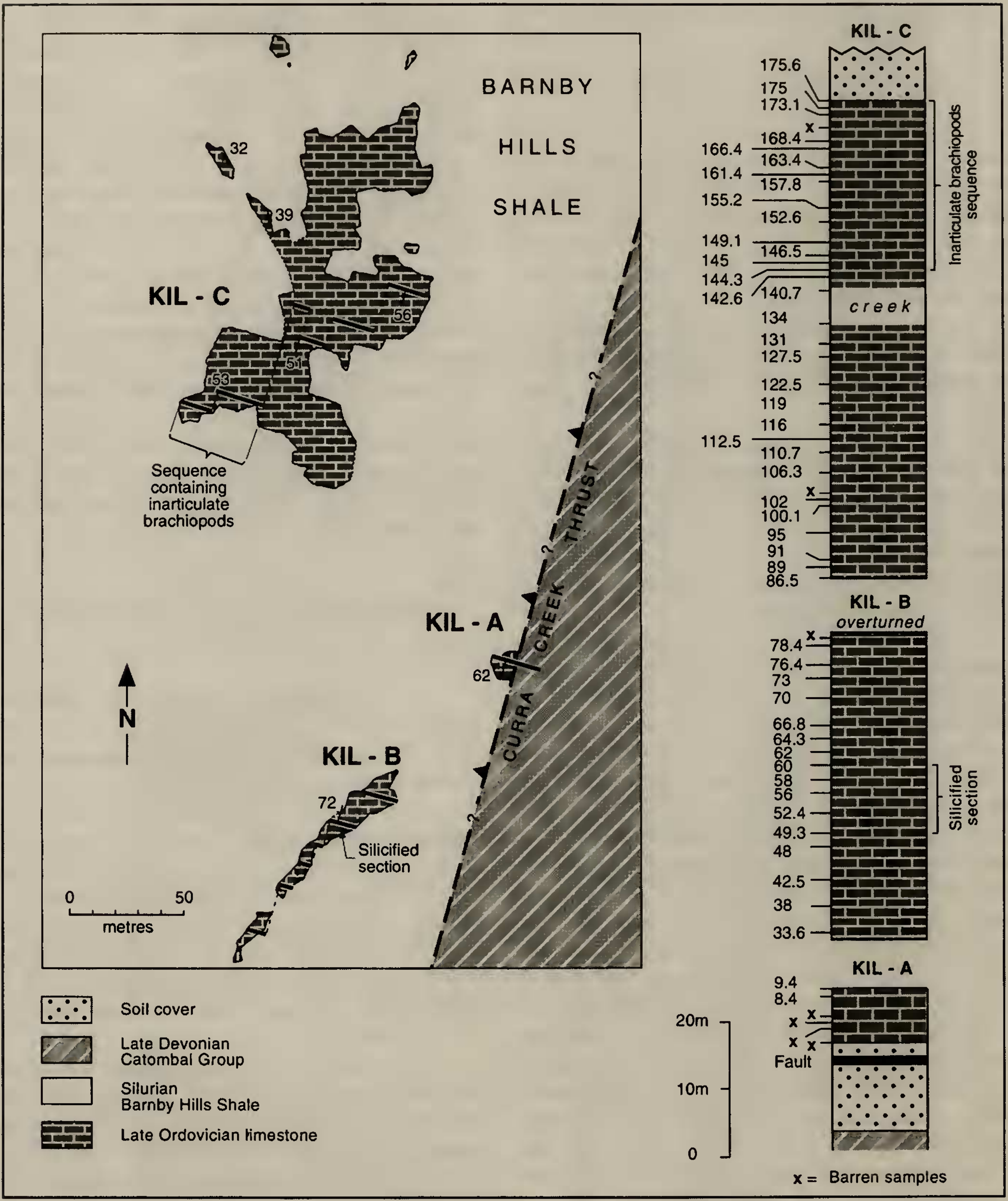

Figure 2. Detailed outcrop map of, and stratigraphic sections measured through, three limestone blocks 'KIL-A', 'KIL-B' and 'KIL-C'; samples producing conodonts are listed to the left of the columns.

extremely rare. Only a few tabulate corals, some stromatoporoids, several brachiopods and one gastropod were recorded from other horizons in the allochthonous blocks.

COMPOSITION AND AGE SIGNIFICANCE OF CONODONT FAUNA

Conodonts recovered from nine individual limestone blocks are represented by 28 species (Fig. 3), and show that these blocks are more or less similar in age (early Eastonian). Twenty-six of these species were previously recorded from the Cliefden Caves Limestone Group (Zhen and Webby 1995), Bowan Park Group (Zhen et al. 1999), Reedy Creek Limestone (Percival, Morgan and Scott 1999), and various other Eastonian successions in central New South Wales (Percival 1999; Packham et al. 1999; Pickett and Furey-Greig 2000; Pickett and Percival 2001), the New England Fold Belt (Furey-Greig 1999, 2000a, 2000b), and eastern Queensland (Palmieri 1978; Simpson 1997). *Coelocerodontus trigonius* Ethington, 1959 and *Panderodus serratus* Rexroad, 1967 are recorded from the Ordovician of eastern Australia for the first time; both are relatively rare, but had a long biostratigraphical range, and are widely distributed.

The six most common species in the fauna - *Panderodus gracilis* (37% of elements), *Belodina confluens* (14%), *Periodon grandis* (12%), *Panderodus* sp. (7%), *Paroistodus*? *nowlani* (6%), and *Yaoxianognathus*? *tunguskaensis* (5%) - are all cosmopolitan or widely distributed geographically. Biostratigraphically significant species present include *Y.*? *tunguskaensis*, which seems to be confined to Eastonian strata of central New South Wales (Trotter and Webby 1995, Zhen and Webby 1995, Zhen et al. 1999), or time equivalents in North China (Wang and Luo 1984; An and Zheng 1990), northwestern China (Wang and Qi 2001), Siberian Platform (Moskalenko 1973), and Canada (McCracken 2000). *Chirognathus cliefdenensis* has previously been reported only from Eastonian rocks of eastern Australia, apart from a recent record from the early Eastonian equivalent *confluens* Zone of southern Baffin Island, Canada (McCracken 2000). Typical species of the *Aphelognathus webbyi* biofacies, which characterises the early Eastonian Fossil Hill Limestone of the Cliefden Caves area, are extremely rare in the present collection, with only two specimens of the Pa element referrable to *A. webbyi* Savage, 1990. *Webbygnathus munusculum* was probably endemic to eastern Australia, with an age range from Ea2 in central New South Wales to Ea3 in the New England Fold Belt (Pickett and Furey-Greig 2000).

Of particular note is the recovery of three species of the Eastonian genus *Taoqupognathus* (*T. philipi*, *T. blandus* and *T. tumidus*) from the 'KIL' locality, where three outcrops were mapped (Fig. 2) and sampled for conodonts (Figs 2 and 3). Zhen and Webby (1995) proposed a lineage for this genus from *T. philipi* to *T. blandus* to *T. tumidus*, which are now recognised as three succeeding conodont zones in the Eastonian (Zhen 2001). *Taoqupognathus blandus* is much more common than the other two species, and indicates an early Eastonian age for these allochthonous limestone blocks in the Barnby Hills Shale. *Taoqupognathus tumidus* is very rare and is only represented by one specimen referable to the P element, which was recovered from the basal part of limestone block 'KIL-B'. However, geopetal structures observed in thin sections prepared from samples taken from the silicified section (Fig. 2) indicate that this outcrop is overturned. Therefore, stratigraphically this late Eastonian (Ea3) species occurs in the highest level of this limestone block. Specimens referrable to *T. philipi* have been recovered from the lower part of limestone block 'KIL-C', and two more specimens doubtfully referred to *T. philipi* are recognised in the two samples of limestone block 'KIL-B'. Occurrence of *T. blandus* and *W. munusculum* in other samples from the same stratigraphic horizon or below suggest that *T. philipi* might well extend upwards into the *T. blandus* Zone or even *T. tumidus* Zone as a relic species (Zhen 2001). Therefore, despite the occurrence of *T. philipi* in some samples, a mid Eastonian (Ea2) age (*T. blandus* Zone) is postulated for the majority of the allochthonous limestone blocks.

BRACHIOPOD FAUNA OF THE ALLOCHTHONOUS BLOCKS

Brachiopods recovered from the silicified portion of the 'KIL-B' section (Fig. 2) include: *Mabella halis*, *Doleroides mixticius*, *Rhynchotrema oepiki*, *Australispira disticha*, *Sowerbyella billabongensis*, with rare *Sowerbyites isotes*, *Zygospira carinata*, *Protozyga definitiva*, *Skenidioides quondongensis*? and *Chaganella speciosa*, together with an indeterminate form provisionally identified as a craniid. All named species recorded here had previously been described (Percival 1991) from *in situ* Eastonian limestones in the Molong Volcanic Belt, such as the Cliefden Caves Limestone Subgroup and the Bowan Park Group, and the Billabong Creek Limestone in the Junee-Narromine Volcanic Belt to the west. Closest correlation is with Brachiopod Fauna B of Ea2 age (Percival 1992), as indicated by the presence of *D. mixticius* and *Sowerbyella billabongensis* which make their first appearances at this level.

Mabella halis and *D. mixticius* overwhelmingly dominate the brachiopod fauna. While *M. halis* is ubiquitous throughout the Eastonian of the central Lachlan Orogen, *D. mixticius* is common only in the Billabong Creek Limestone. Another significant species, previously believed to be restricted to this latter formation, is *S. billabongensis*. On the other hand, two of the rare species in the allochthonous block fauna – *Skenidioides quondongensis*? and *C. speciosa* (represented by a solitary fragmentary specimen) – are otherwise known only from the Molong Volcanic Belt. However, given the location of the Eurimbla area in this Belt, this is not unexpected. The occurrence of *S. billabongensis* in the Eurimbla allochthonous blocks is unusual; seen in the context of the presence of the conodont *Webbygnathus munusculum*, which also is unknown in any other Molong Volcanic Belt limestone, this suggests the possibility of a linkage between the Junee-Narromine Volcanic Belt and the western flank of the northern Molong Volcanic Belt. However, affinities of the majority of the conodont fauna, discussed below, indicate likely derivation of the limestone blocks from a more proximal source area.

STRUCTURAL AND DEPOSITIONAL SETTINGS

To determine the most likely potential source of the allochthonous blocks, an analysis was undertaken of contemporaneous conodont faunas known from Eastonian limestones of the Molong Volcanic Belt. Many species are common to these *in situ* limestones and the allochthonous blocks, but it is the presence or absence of certain restricted species which is critical to revealing closest affinities. The nearest known *in situ* carbonate of Late Ordovician age, which might have provided a potential source area for the Eurimbla blocks, is the Reedy Creek Limestone, exposed near Molong about 20 kms to the south (Percival, Morgan and Scott 1999). The Reedy Creek conodont fauna is almost an exact duplicate of the more fully documented fauna from the Cliefden Caves Limestone Group, described by Zhen and Webby (1995). The latter shares 18 of the 28 species in the allochthonous assemblages, but significantly lacks *Paroistodus*? *nowlani* and *Protopanderodus liripipus*. Both of these species are present in allochthonous limestones near the base of the overlying Malongulli Formation (Trotter and Webby 1995), which is of slightly younger Ea3 age. However, the basal Malongulli Formation fauna is apparently devoid of *Chirognathus cliefdenensis*, *Taoqupognathus blandus*, *T. philipi* and *Yaoxianognathus wrighti*, which are regarded as biostratigraphically important species. The Bowan Park Group fauna (Zhen et al. 1999), particularly that of the Quondong Limestone (Eastonian 2 age), has more species in common with the Eurimbla allochthonous blocks than do the previously mentioned faunas. Thus the affinities of the Eurimbla faunas are closer to *in situ* carbonates on the western flank of the Molong Volcanic Belt, rather than with the Reedy Creek Limestone, contrary to what might have been expected from the latter's geographical proximity.

The presence of *Webbygnathus munusculum*, although extremely rare in the Eurimbla allochthonous blocks (a single specimen recovered from 'KIL-C'), is of some importance in being the first record of the taxon from the Molong Volcanic Belt. Pickett and Furey-Greig (2000), who described this species from Eastonian 2 horizons in the Billabong Creek Limestone of the Junee-Narromine Volcanic Belt, and Ea3 strata in the New England Orogen, commented that "curiously" their new monotypic genus had not been reported from any of the extensive assemblages (discussed above) described from the Molong Volcanic Belt. Hence it is worthwhile investigating other affinities between the conodont faunas from allochthonous limestones at Eurimbla with those from the upper Billabong Creek Limestone (itself in part an allochthonous horizon, although this was deposited penecontemporaneously with the surrounding sediments). A number of significant species found in the Eurimbla allochthonous blocks were not recorded from the Gunningbland area by Pickett and Percival (2001), particularly *Paroistodus*? *nowlani*, *Protopanderodus liripipus*, *Pseudobelodina dispansa*, *Taoqupognathus philipi* and *Yaoxianognathus wrighti*. Thus we conclude that the Billabong Creek Limestone is perhaps not as strong a contender as is the Bowan Park area for a potential source of the Eurimbla allochthonous blocks, and the presence of *Webbygnathus munusculum* in the latter remains enigmatic.

Other erosional remnants in the nearby region are represented by Late Ordovician limestones in the Sourges Shale (Percival, Morgan and Scott 1999), especially the limestone containing conodont sample C1547 that is interpreted as having a middle Eastonian (Ea2-3) age. This outcrop is located about 3 km northeast of Cumnock, and is approximately 6 km west of the Eurimbla allochthonous blocks. Almost due north of the Eurimbla area, along regional strike, further evidence of Late Ordovician allochthonous limestones is found at "Narrawa" in the Wellington district (Percival, Morgan and Scott 1999). This particular occurrence yields corals of coral-stromatoporoid Fauna III age, together with an undescribed inarticulate (lingulate and acrotretid) brachiopod fauna containing several elements in common with the fauna found at 'KIL-C' at Eurimbla. The associated conodont fauna at "Narrawa" is sparse, but includes *Periodon grandis* and *Protopanderodus liripipus*, both of which are represented at Eurimbla. These allochthonous blocks appear to have been emplaced into the Oakdale Formation, here of similar Late Ordovician (late Eastonian to early Bolindian) age.

Allochthonous limestones of Late Ordovician age have also been reported from the Apsley and Bodangora areas, approximately 5 kms SSE and 15 kms NNE, respectively, from Wellington. The Apsley block, located about 400 m E of the railway crossing, is apparently surrounded by Early Devonian Cuga Burga Volcanics. Conodonts recovered from this limestone (collection of the late G.C.O. Bischoff) included *Yaoxianognathus*, *Periodon grandis*, *Panderodus*, and *Taoqupognathus blandus*, indicative of an Eastonian 2 age – identical to that interpreted for the Eurimbla blocks. The Bodangora occurrence is shown on the most recent mapping by the Geological Survey of N.S.W. as an elongate limestone block within the Oakdale Formation at GR 685800E 6409500N (Dubbo 1:100,000 mapsheet). Geological Survey microfossil sample C 061 yielded a small assemblage including the following conodonts: *Belodina confluens*, *Panderodus gracilis*, *Protopanderodus liripipus* and *Taoqupognathus* sp., which can be dated no more accurately than Eastonian.

Having established the age of the Eurimbla allochthonous blocks as early Eastonian (Ea2), and their most likely source as the Bowan Park Group, based on overall similarities in conodont faunas, the mechanism of their emplacement in the Barnby Hills Shale remains to be determined. Clumping of the limestone blocks in three separate groups, two to three kilometres apart, may reflect the presence of discrete channels or submarine valleys. The blocks are also emplaced at various stratigraphic levels within the Barnby Hills Shale, indicating that erosion and redeposition of material was not confined to a single episode. Timing of this series of events is constrained only by the age of the enclosing sediments, ie middle? to late Wenlock to mid Ludlow.

In one possible scenario, the former Molong Volcanic Belt (in which the Bowan Park Group was deposited in the Late Ordovician) subsided in the Early Silurian, becoming the site for further shallow water sedimentation along the Molong High. Uplift of this area, concurrent with deposition of the Barnby Hills Shale in late Wenlock to mid Ludlow time, would have led to erosion of the Molong High succession and emplacement of allochthonous blocks in the deeper water sediments flanking that tectonic feature. The lack of carbonate debris forming breccia deposits within the Barnby Hills Shale in the study area suggests that the limestone blocks either slid down slope individually, or else were associated with a mass flow deposit but, due to their momentum, travelled further into deeper water after the bulk of finer-grained debris had settled. This model pre-supposes that only Eastonian limestone was available at the source site and that any carbonate material aged between Eastonian and the onset of deposition of the Barnby Hills Shale was either not present or had previously been eroded away.

However, elsewhere in central New South Wales, Sherwin (1971) reported allochthonous blocks of Late Ordovician Malongulli Formation and Reedy Creek Limestone redeposited in the Wallace Shale of Late Silurian age, at "Mirrabooka" near Molong. In this instance, blocks with intervening ages are known to have been reworked into the succession, with detritus (including boulder beds) eroded from progressively older deposits. Thus clasts derived from the early Ludlow Molong Limestone appear lower in the Wallace Shale, to be succeeded by the Late Ordovician olistoliths as the Mirrabooka submarine valley (Byrnes 1976; Byrnes *in* Pickett 1982: 159, figs 19, 20) excavated through the western shelf edge of the northern Molong Rise.

Along the eastern margin of the Molong Rise, allochthonous block deposition in Late Silurian to Early Devonian fill of the Hill End Trough (Talent and Mawson 1999) derived from erosion of rocks forming the platform margin to the Mumbil Shelf. This was exposed during the Late Silurian, allowing limestone blocks of various sizes to detach and redeposit in the mud and silt matrix of a lower slope to basinal setting. Again, in this well-documented example, a considerable variety of ages of redeposited blocks, from late Wenlock to Emsian, are evident (Talent and Mawson 1999: text-fig. 7), which is at variance with the Eurimbla situation.

An alternative model to account for the lack of any allochthonous Early Silurian carbonate material, involves tectonic uplift with multiple episodes of redeposition – the first concurrent with limestone breccias emplaced into the basal Malongulli Formation in the Cliefden Caves area (Rigby and Webby 1988). The source of these limestones is interpreted as the Ballingoole Limestone (Eastonian 3 age) in the upper Bowan Park Group. In the northern Molong Volcanic Belt, the Eurimbla blocks appear to have been derived from the slightly older Quondong Limestone, with initial emplacement in the deeper water Oakdale Formation flanking the volcanic belt. Subsequent tectonic uplift of this unit would lead to a second erosional episode in which only the more competent limestones were redeposited as recognisable clasts into the Barnby Hills Shale. This may explain removal of associated finer-grained carbonate debris to leave only the larger blocks in the final depositional episode.

Large-scale faulting on the Curra Creek Thrust and related structures to the west (Scott and Glen 1999; Glen 1999: fig. 95) provides a possible mechanism to explain the occurrence of allochthonous blocks in the Barnby Hills Shale, by bringing Late Ordovician sediments to sufficiently shallow depths to expose them directly to subaerial or submarine erosion without having to wear through Early Silurian cover. In the extensional tectonic regime prevailing in the region during the Silurian, it is probable that some rotational component was involved in such faulting (R.A. Glen, pers. comm.). Further south on the Bathurst 1:250 000 sheet, the Columbine Mountain Fault (Glen 1998: 302) defines the present-day crest of the preserved Molong Volcanic Belt, separating its western side (where the Bowan Park Group was deposited) from the eastern flank, site of the Cliefden Caves Limestone Subgroup and Reedy Creek Limestone. Webby (1992: 56) invoked early movement on the Columbine Mountain Fault as responsible for subsidence of the eastern flank while shallow water carbonate deposition continued in the Bowan Park area, the latter shedding debris into the deep water Malongulli Formation. Timing of this tectonic activity coincides with emplacement of shallow water carbonate blocks into the Oakdale Formation in the Wellington region, and quite feasibly caused displacement of Quondong Limestone equivalents into deeper water sediments.

MATERIAL AND METHODS

Five larger limestone bodies were measured and sampled, and a further four limestone bodies were also spot-sampled (Figs 1 and 2). The majority of conodont samples came from two measured sections through limestone blocks 'KIL-B' (16 samples) and 'KIL-C' (28 samples) (Figs 2 and 3). These samples, each weighing approximately 6 kg, were collected at regular intervals along the measured sections. Conodonts were extracted by completely dissolving the samples in dilute (10%) acetic acid; the residues were separated using the Sodium polytungstate technique outlined in Anderson et al. (1995). Sixty-five samples yielded a total of 1884 conodont elements (Fig. 3), which are relatively well preserved with a CAI of 4. Photographs of the conodonts are SEM photomicrographs captured digitally. Figured conodont specimens bearing the prefix AMF are deposited in the Australian Museum, Sydney. The majority of the conodont species identified are documented by illustration only, as comparable material has been adequately described in recent publications on Late Ordovician conodont faunas of central-western NSW. Only those species providing new or comparative taxonomic information are discussed in detail in the following section.

Brachiopods were obtained by acid dissolution of silicified horizons from limestone block 'KIL'. Illustrated brachiopods are housed in the Palaeontological Collections of the Geological Survey of New South Wales at Lidcombe, and have the prefix MMF. Silicified specimens were not whitened prior to being photographed digitally. As all taxa recognised, with the exception of a possible craniid, were comprehensively described by Percival (1991), only brief remarks are made on significant species.

Grid references of the sampled localities (all on Cumnock 8632-S 1:50,000 sheet, using AMG66 co-ordinates) are as follows: 'KIL-A': 674000E 6358850N, 'KIL-B': 673950E 6358800N, 'KIL-C': 673900E 6358950N, 'KILS': 673850E 6357900N, 'CWNN': 673600E 6357400N, 'KILN': 674350E 6361700N, 'WKILN' (top): 674350E 6362000N, 'FT': 674500E 6362100N, and 'EURO': 674350E 6364650N.

SYSTEMATIC PALAEONTOLOGY

[Conodont taxonomy by Zhen; brachiopod taxonomy by Percival]

Phylum CHORDATA Bateson, 1886
Class CONODONTATA Pander, 1856
Genus CHIROGNATHUS Branson and Mehl, 1933

Type species

Chirognathus duodactylus Branson and Mehl, 1933.

Chirognathus? *cliefdenensis* Zhen
and Webby, 1995
Fig. 5A-C

Synonymy

?*Oulodus* cf. *oregonia* (Branson, Mehl and Branson): Trotter and Webby, 1995, p. 483, pl. 4, figs 16-17.

Chirognathus cliefdenensis Zhen and Webby, 1995, p. 281, *partim*, pl. 2, figs 13-22, pl. 3, figs 2-4; non pl. 3, fig. 1; Zhen et al., 1999, p. 86, Fig. 6.13-17.

Yaoxianognathus? *tunguskaensis* (Moskalenko): McCracken, 2000, *partim*, only pl. 3, figs ?26, 28-30.

limestone bodies	KIL-A		KIL-B															
Samples Conodont taxa	KIL8.4	KIL9.4	KIL33.6	KIL38	KIL42.5	KIL48	KIL49.3	KIL52.4	KIL56	KIL58	KIL60	KIL62	KIL64 3	KIL66.8	KIL70	KIL73	KIL76.4	KIL78 4
Ansella sp.		1			1													2
Aphelognathus webbyi																		
Belodina baiyanhuaensis						4		2						2				
Belodina confluens	2	7	2		5	5	1	3	1	2	2	6	2	2	9	4	4	7
Belodina sp.						4	1		1					2				
Besselodus sp.																		
Chirognathus? cliefdenensis					1										1			2
Coelocerodontus trigonius		2											1					
Drepanoistodus suberectus		1				1						2			3			
"*Oistodus*" sp. cf. *venustus*					1	1		1										1
Panderodus gracilis	2	2	7	1	12	8	3	7	2	5	3	2	2	6	7	4	3	7
Panderodus panderi					1													
Panderodus serratus															1			
Panderodus sp.		7		2	3	7	2			1	4		2	2	3			
Paroistodus? nowlani	1															2		
Periodon grandis																		
Phragmodus undatus											2				1	1		
Protopanderodus liripipus																1		
Pseudobelodina dispansa														1	1			
Pseudobelodina sp.																		
Pseudooneotodus mitratus									1									
Taoqupognathus blandus	2				1						3							1
Taoqupognathus philipi			1?												1?			
Taoqupognathus tumidus				1														
Webbygnathus munusculum																		
Yaoxianognathus wrighti						1												
Y.? tunguskaensis	1	2			2	4	1		1			1	3		2	2		4
Yaoxianognathus sp.						1												
TOTAL	9	22	10	4	27	36	8	13	6	8	14	11	10	15	29	14	7	24

limestone bodies	KIL-C																											
Samples Conodont taxa	KIL86 5	KIL89	KIL91	KIL95	KIL95.7	KIL97.5	KIL100.1	KIL102	KIL106.3	KIL110.7	KIL112 5	KIL116	KIL119 5	KIL134	KIL142.6	KIL144.3	KIL145	KIL146.5	KIL149.1	KIL152.6	KIL155.2	KIL157.8	KIL161.4	KIL166.4	KIL168.4	KIL173.1	KIL175	KIL175.6
Ansella sp.		1																			1	1			2	1		1
Aphelognathus webbyi																								1				
Belodina baiyanhuaensis			1		2						1						1											
Belodina confluens	10	26	4	27	8	3		5	6	3	3		2			1	8	1	1	4	3	5	2	12	9	13		6
Belodina sp.				2																			1					
Besselodus sp.																							2	2				1
Chirognathus? cliefdenensis		1		2			1					2					2									1		
Coelocerodontus trigonius									1																	4		
Drepanoistodus suberectus	1	1		1	1										1		1	1	1	5	2	9	7	9	7	6		2
"*Oistodus*" sp. cf. *venustus*	2									1					2		2			4			1			13		5
Panderodus gracilis	8	26	1	16	4	7	28	2	11	4	2	5	11	20	6	12	37	11	17	28	31	17	35	38	54	34	1	48
Panderodus panderi																								2				2
Panderodus serratus																							1			3		1
Panderodus sp.	2	2	7				4		6	2	2		5	1		3	7	1	4	6	3		4	4	9			2
Paroistodus? nowlani	1														2	1	9	1	3	15	12	8	3	17	17	17		6
Periodon grandis																	2			1	2	9	3	54	11	93		35
Phragmodus undatus				2	1		2	3																		1		
Protopanderodus liripipus													1								1			2		7		5
Pseudobelodina dispansa	2	4		2			3		1			1					1			3								
Pseudobelodina sp.																												
Pseudooneotodus mitratus																										5		2
Taoqupognathus blandus			1		2										2	1	6	1	2	2	2			2	2	4		
Taoqupognathus philipi						2	16		2				2															
Taoqupognathus tumidus																												
Webbygnathus munusculum				1																								
Yaoxianognathus wrighti																				2		7			2			
Y.? tunguskaensis	5	10	1	7			9			1			2		4				1	1			2	9	6	4		4
Yaoxianognathus sp.							1	1																				
TOTAL	31	71	15	60	18	12	64	11	27	11	8	8	23	21	17	18	76	16	28	71	57	56	61	150	119	206	1	119

limestone bodies	FT						KILN				CWNN	KILS	WKILN				EURO			TOTAL
Samples Conodont taxa	FT40	FT45	FT51	FT68	FT73	FT84	KILN10	KILN17	KILN40	KILN52			WKILN-A	WKILN-B	WKILN-C	WKILN-D	EURO (top)	EURO (mid)	EURO (base)	
Ansella sp.															1					12
Aphelognathus webbyi												1								2
Belodina baiyanhuaensis										3										16
Belodina confluens	1			2		3	3		3		1	5	5		6		8		1	264
Belodina sp.																				11
Besselodus sp.										1								2		8
Chirognathus? cliefdenensis			1					1												15
Coelocerodontus trigonius																				8
Drepanoistodus suberectus			1								1		9		1	1		1		76
"*Oistodus*" sp. cf. *venustus*														1						35
Panderodus gracilis		1	7	6	3	5	2		8	12	20	2	23	1	10	9	5	1	1	703
Panderodus panderi																				5
Panderodus serratus																				6
Panderodus sp.	1		2							1	6		2		5	2	1			127
Paroistodus? nowlani										1			6		1			2	1?	120
Periodon grandis													18		2					230
Phragmodus undatus				1																14
Protopanderodus liripipus																				17
Pseudobelodina dispansa		1																		20
Pseudobelodina sp.															1					1
Pseudooneotodus mitratus																				8
Taoqupognathus blandus	1			1		1				1				1	1			1		41
Taoqupognathus philipi																				24
Taoqupognathus tumidus																				1
Webbygnathus munusculum																				1
Yaoxianognathus wrighti										1								1		14
Y.? tunguskaensis										2	1		3		1	2		2		100
Yaoxianognathus sp.				1									1							5
TOTAL	3	2	11	11	3	9	5	1	11	21	29	8	67	3	29	14	14	8	3	1884

Figure 3. Distribution chart of conodont species from nine individually sampled allochthonous limestone blocks.

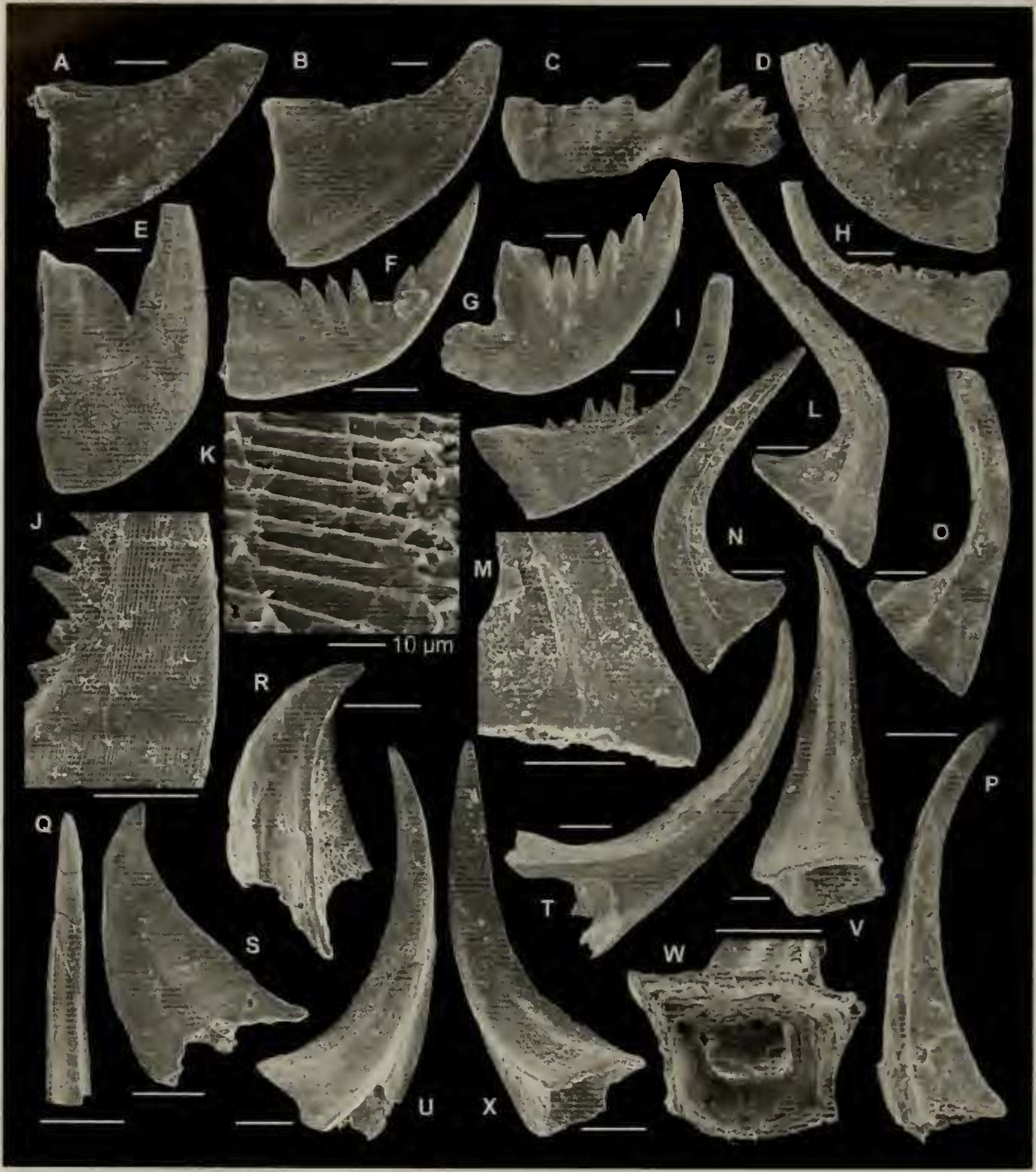

Figure 4. SEM photographs of Late Ordovician conodonts from allochthonous limestones within the Barnby Hills Shale. **A, B**, *Ansella* sp., asymmetrical nondenticulated element; A, AMF121400, 'KIL' 9.4; B, AMF121401, 'KIL' 95. **C**, *Aphelognathus webbyi* Savage, 1990, Pa element, AMF121402, 'KILS'. **D**, *Belodina baiyanhuanensis* Qiu *in* Lin et al., 1984, compressiform element, AMF121403, 'KILN' 52. **E-G**, *Belodina confluens* Sweet, 1979, E, eobelodiniform element, AMF121404, 'KIL' 97.5; F, grandiform element, AMF121405, 'KIL' 70; G, compressiform element, AMF121406, 'KIL' 173.1. **H-K**, *Belodina* sp., grandiform element; H, AMF121407, 'KIL' 56; I, J, AMF121408, 'KIL' 48; K, enlargement of surficial ornament, AMF121409, 'KIL' 49.3. **L-O**, *Besselodus* sp., short-based distacodiform element; L, M, AMF121410, 'KIL' 161.4; N, AMF121411, 'KILN' 52; O, AMF121412, 'KIL' 161.4. **P-X**, *Coelocerodontus trigonius* Ethington, 1959; P, Q, symmetrical trigoniform element, P, AMF121413, 'KIL' 173.1; Q, AMF121414, 'KIL' 9.4; R, S, asymmetrical trigoniform element, AMF121415, 'KIL' 173.1; T, U, asymmetrical tetragoniform element, AMF121416, 'KIL' 173.1; V-X, symmetrical tetragoniform element (W: basal view), AMF121417, 'KIL' 173.1; scale bars 100 µm, except as indicated for K.

Material

Fifteen specimens (6 Pa, 4 Pb, 5 S) from limestone blocks 'KIL-B', 'KIL-C', 'FT' and 'KILN'.

Discussion

All elements, except for the symmetrical Sa, have been recovered from various limestone blocks within the Barnby Hills Shale, and they are identical with the type material from the Cliefden Caves Limestone Group (Zhen and Webby 1995).

McCracken (2000) proposed a septimembrate apparatus for *Yaoxianognathus*? *tunguskaensis* (Moskalenko). This reconstruction is rather different from that recognised by Zhen et al. (1999) on the basis of homologic characters, such as widely spaced, robust denticles on all elements of *Y.*? *tunguskaensis*. McCracken's illustrated Sc and M elements of *Y.*? *tunguskaensis* are typical for *Yaoxianognathus*, especially the Sc (McCracken 2000: pl. 3, fig. 25) which is referable to *Y. tunguskaensis*. However, P (Pa, Pb, Pc) and Sa elements figured by McCracken (2000: pl. 3, figs 26, 28-30) are at least congeneric if not conspecific with *C. cliefdenensis*.

Genus COELOCERODONTUS Ethington, 1959

Type species

Coelocerodontus trigonius Ethington, 1959.

Coelocerodontus trigonius Ethington, 1959
Fig.4P-X

Synonymy

Coelocerodontus trigonius Ethington, 1959, p. 273, pl. 39, fig. 14; Webers, 1966, p. 25, pl. 2, figs 12-14; ?Orchard, 1980, p. 19, pl. 2, figs 17, 22, 23, 29; Nowlan et al., 1988, p. 14, pl. 3, figs 1-5, 8-10 (cum. syn.); McCracken and Nowlan, 1989, p. 1888, pl. 2, fig. 18; Nowlan et al., 1997, pl. 1, fig. 4; Zhang, 1998, p. 56, pl. 5, figs 1-4.

Coelocerodontus tetragonius Ethington, 1959, p. 273, pl. 39, fig. 15.

Coelocerodontus digonius Sweet and Bergström, 1962, p. 1224, pl. 168, fig. 1, Text-fig. 1F.

Material

Eight specimens (6 trigoniform, 2 tetragoniform) from limestone blocks 'KIL-A', 'KIL-B' and 'KIL-C'.

Discussion

Webers' (1966) initial species concept of a bimembrate (trigoniform and tetragoniform) apparatus was revised by Nowlan et al. (1988) as a trimembrate apparatus including a symmetrical trigoniform, a slightly asymmetrical trigoniform and a nearly symmetrical tetragoniform element. All three elements have been recognised in the central New South Wales material, together with an additional slightly asymmetrical tetragoniform specimen. All these elements are characterised by having thin walls and a very deep basal cavity, with the apex nearly reaching the tip of the cusp. The trigoniform elements, with a broad anterior face, a sharp costa on each antero-lateral corner, and a costa along the posterior margin, are either symmetrical (Fig. 4P, Q) or slightly asymmetrical (Fig._4R, S), with a triangular opening of the basal cavity. The latter is identical with the holotype of the form species *C. trigonius*, except for its more antero-posteriorly compressed cusp. The tetragoniform element is quadrate in cross section with four prominent costae, situated on the antero-lateral and postero-lateral corners of each side. Our specimens are identical with the holotype of the form species *C. tetragonius* Ethington, 1959, except that the latter (Ethington 1959: pl. 39, fig. 15) is more laterally compressed.

Zhang (1998) illustrated (but neither defined nor described) laterally compressed, non-costate P elements, and costate Sb, Sc and Sd elements from the Middle Ordovician of South China. Of the two specimens (Zhang 1998: pl. 5, figs 1, 2) referred to as P elements, the more slender is identical with the holotype of the form species *C. digonius* Sweet and Bergström, 1962. The other specimen (Zhang 1998: pl. 5, fig. 1) is a wider conical unit with a more posteriorly extended base. These elements may be differentiated as Pa and Pb, respectively. The specimen designated as the Sd element (Zhang 1998: pl. 5, fig. 4) seems identical with one illustrated as *Coelocerodontus*? sp. from the Middle Ordovician (Darriwilian) of northern Sweden (Löfgren 1978: pl. 1, fig. 40). Neither the P elements, nor the Sd element with a mid-costa on each side, have been recognised in the central New South Wales material.

Coelocerodontus trigonius ranged through the Middle and Upper Ordovician. The type specimen (Ethington 1959: pl. 39, fig. 14) from the upper Galena Formation (*confluens* Zone) of Iowa is associated with a rich conodont fauna including *Belodina confluens*, *Phragmodus undatus*, *Periodon grandis*, and *Drepanoistodus suberectus*. Zhang (1998) reported this species from the Middle Ordovician Guniutan Formation (Darriwilian) of South China. It was also identified from the Upper Ordovician of North America (Winder 1966; Webers 1966; Nowlan et al. 1988, 1997; McCracken and Nowlan 1989), Scandinavia (Hamer 1964) and north England (Orchard 1980). This is the first record of this species in the Ordovician of eastern Australia.

Figure 5. SEM photographs of Late Ordovician conodonts from allochthonous limestones within the Barnby Hills Shale. **A-C**, *Chirognathus*? *cliefdenensis* Zhen and Webby, 1995; A, Pa element, AMF121418, 'CWNN'; B, Sd element, AMF121419, 'KIL' 78.4; C, Sc element, AMF121420, 'KIL' 78.4. **D-I**, *Drepanoistodus suberectus* (Branson and Mehl, 1933); D, M element, AMF121421, 'KIL' 86.5; E, Sb element, AMF121422, 'KIL' 62; F, Sa element, AMF121423, 'KIL' 157.8; G, P element, AMF121424, 'KIL' 155.2; H, Sc element, AMF121425, 'KIL' 157.8; I, Sa element, AMF121426, 'KIL' 95.7. **J**, "*Oistodus*" sp. cf. *venustus* Stauffer, 1935 s.f., M element, AMF121427, 'KIL' 110.7. **K-M**, *Panderodus gracilis* (Branson and Mehl, 1933); K, falciform element, AMF121428, 'KIL' 175.6; L, M, asymmetrical graciliform element, L, AMF121429, 'KIL' 175.6, M, AMF121430, 'CWNN'. **N, O**, *Panderodus panderi* (Stauffer, 1940); N, short-based element, AMF121431, 'KIL' 175.6; O, long-based element, AMF121432, 'KIL' 175.6. **P-T**, *Panderodus serratus* Rexroad, 1967; P, S, T, serrated arcuatiform element, P, AMF121433, 'KIL' 173.1, S, AMF121435, 'KIL' 175.6, T, AMF121436, 'KIL' 173.1; Q, R, non-serrated falciform element, AMF121434, 'KIL' 173.1. **U-W**, *Panderodus* sp.; falciform element, U, AMF121437, 'KIL' 175.6; V, AMF121438, 'KIL' 175.6; W, AMF121439, 'CWNN'; scale bars 100 μm.

Genus DREPANOISTODUS Lindström, 1971

Type species

Oistodus forceps Lindström, 1955.

Drepanoistodus suberectus (Branson and Mehl, 1933)
Fig. 5D-I

Synonymy

Oistodus suberectus Branson and Mehl, 1933, p. 111, pl. 35, figs 22-27.

Drepanoistodus suberectus (Branson and Mehl); Nowlan and McCracken *in* Nowlan et al., 1988, p. 16, pl. 3, figs 19-22 (*cum syn.*); Dzik, 1994, p. 78, pl. 17, figs 2-6, text-fig. 12b; Zhen and Webby, 1995, p. 282, pl. 3, figs 8-10 (*cum syn.*); Nowlan et al., 1997, pl. 1, figs 7-9; Zhen et al., 1999, p. 88, Fig. 6.1-7; Furey-Greig, 1999, p. 310, pl. 2, figs1-3; Furey-Greig, 2000b, p. 137, Fig. 5.8; McCracken, 2000, pl. 1, fig. 12, pl. 2, figs 20, 21; Leslie, 2000, Fig. 5.16-19; Sweet, 2000, Fig. 9.23-25.

Material

Seventy-six specimens (9 P, 6 M, 5 Sa, 12 Sb, 10 Sc and 34 undifferentiated elements) from limestone blocks 'KIL-A', 'KIL-B', 'KIL-C', 'FT', 'CWNN', 'WKILN' and 'EURO'.

Discussion

Elements forming the quinquimembrate apparatus of this species are laterally compressed, with sharp posterior and anterior margins and smooth lateral faces. The P element is weakly asymmetrical with a convex outer lateral face and an inner-laterally curved cusp, and is characterised by having a triangular, anticusp-like extension at the antero-basal corner. The M element is geniculate with a robust cusp. The nearly symmetrical Sa element has a sub-erect cusp, an antero-posteriorly extended base, and a shallow, but open inflated basal cavity. The Sb element is asymmetrical, with a suberect to slightly reclined cusp, a strongly curved basal margin, and the base extended only posteriorly. The Sc element somewhat resembles the P element, but is strongly asymmetrical with a posteriorly reclined cusp, and apparently lacks the prominent antero-basal extension of the latter. The present material is identical with that from the Bowan Park Group and basal Malachi's Hill Beds (Zhen et al., 1999), except that the P element from the limestones within Barnby Hill Shale shows a more strongly extended antero-basal corner.

Genus PANDERODUS Ethington, 1959

Type species

Paltodus unicostatus Branson and Mehl, 1933.

Panderodus serratus Rexroad, 1967

Fig. 5P-T

Synonymy

Panderodus unicostatus serratus Rexroad, 1967, p. 47, pl. 4, figs 3, 4.

Panderodus serratus Rexroad; Cooper, 1975, p. 993, pl. 1, figs 3-5, 7-9, 13, 14, 23; Nowlan et al., 1988, p. 23, pl. 8, figs 5-7; Miller, 1995, pl. 1, figs 15, 16; Jeppsson, 1997, p.107, Fig. 7.4.

Material

Six specimens (4 serrated arcuatiform, 2 falciform elements) from limestone blocks 'KIL-B' and 'KIL-C'.

Discussion

Panderodus serratus ranges from the Upper Ordovician (Ethington and Schumacher 1969; McCracken and Barnes 1981; Nowlan and Barnes 1981; Nowlan et al. 1988) where it is relatively rare, through the Lower and Middle Silurian (Miller 1995; Jeppsson 1997), where it is widely distributed although by no means common. The distribution patterns of *Panderodus serratus* and its abundant ubiquitous associate *P. unicostatus* in the Silurian suggested to Jeppsson (1997) that they represented two distinct species (rather than morphotypes of a single species), distinguishable on presence or absence of the serrated element. In our collections, the serrated element is only represented by four specimens, which are comparable with those recorded from the Upper Ordovician of Canada (Nowlan et al. 1988), except for their smaller denticles and more prominently inner laterally curved cusp. Two additional specimens, which are recognised as the nonserrated falciform element of this species, are laterally compressed with sharp anterior and posterior margins.

Genus PERIODON Hadding, 1913

Type species

Periodon aculeatus Hadding, 1913.

Periodon grandis (Ethington, 1959)

Fig. 6D-L

Synonymy

Loxognathus grandis Ethington, 1959, p. 281, pl. 40, fig. 6.

Periodon grandis (Ethington); Bergström and Sweet, 1966, p. 363-5, pl. 30, figs 1-8 (*cum syn.*); Lindström *in* Ziegler, 1981, p. 243-244, *Periodon*-pl. 1, figs 13-18; Zhang and Chen, 1992, pl. 1, figs 13-16; Ding et al., *in* Wang, 1993, p. 190, pl. 35, figs 18-21; Zhen and Webby, 1995, p. 284, pl. 4, figs 3, 4 (*cum syn.*); Zhen et al., 1999, p. 90, fig. 8.19-8.21; Furey-Greig, 1999, p. 310, pl. 2, figs 21, 22, pl. 3, figs 1, 2.

Material

Two hundred and thirty specimens (36 Pa, 8 Pb, 123 M, 63 S elements) from limestone blocks 'KIL-C' and 'WKILN'.

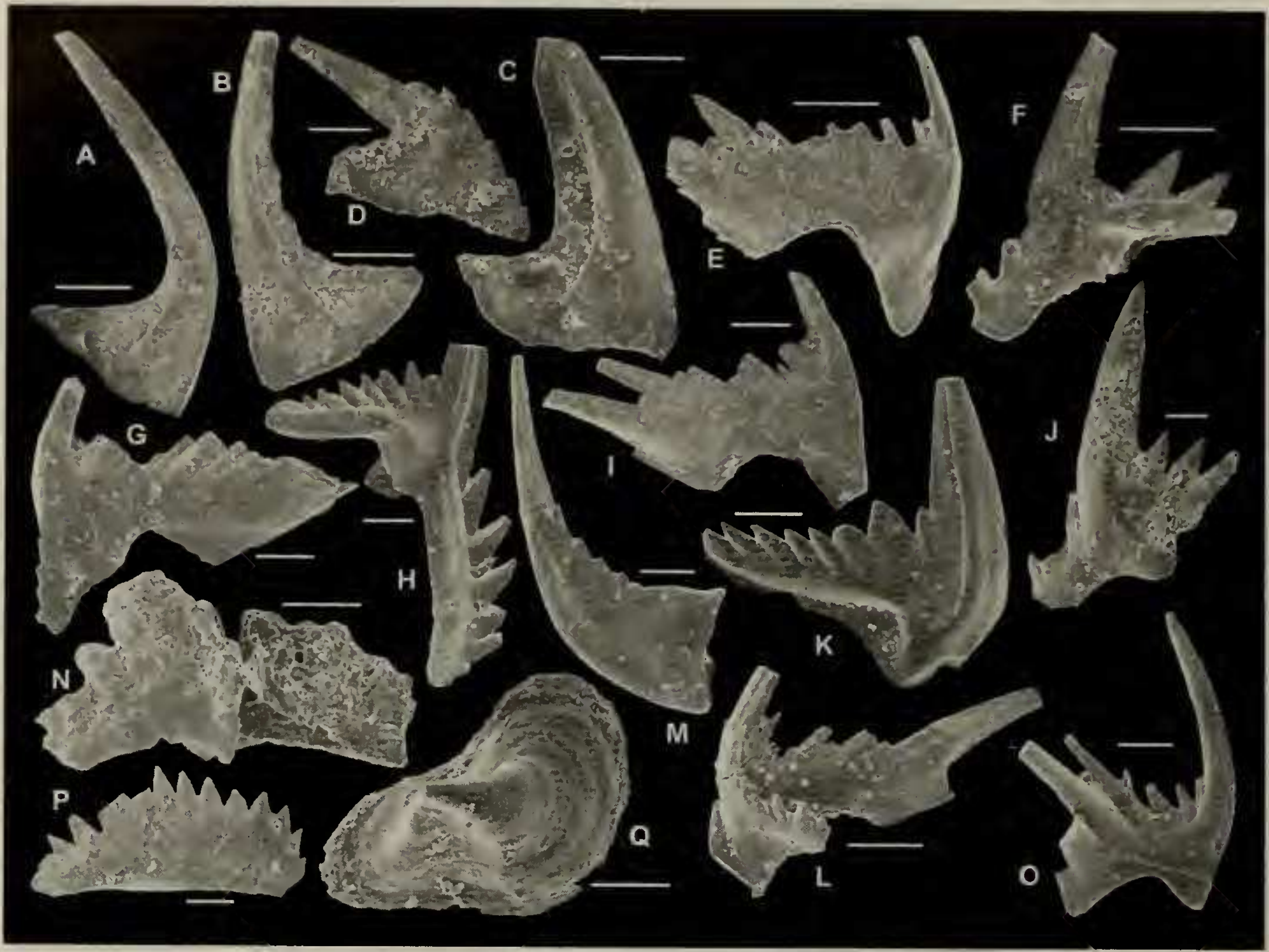

Figure 6. SEM photographs of Late Ordovician conodonts from allochthonous limestones within the Barnby Hills Shale. **A-C**, *Paroistodus*? *nowlani* Zhen et al., 1999; distacodiform (b) element, A, AMF121440, 'KIL' 73; B, AMF121441, 'KIL' 145; C, AMF121442, 'KIL' 149.1. **D-L**, *Periodon grandis* (Ethington, 1959); D, M element, AMF121443, 'KIL' 152.6; E, Sc element, AMF121444, 'KIL' 166.4; F, Pa element AMF121445, 'KIL' 155.2; G, Sb element, AMF121446, 'KIL' 157.8; H, Pb element, AMF121447, 'KIL' 173.1; I, Sc element, AMF121448, 'KIL' 166.4; J, Pa element, AMF121449, 'KIL' 157.8; K, ?Sd element, AMF121450, 'KIL' 173.1; L, Sa element, AMF121451, 'KIL' 173.1. **M,** *Pseudobelodina dispansa* (Glenister, 1957); AMF121452, 'KIL' 70. **N, O,** *Phragmodus undatus* Branson and Mehl, 1933; N, Pa element, AMF121453, 'KIL' 70; O, Sc element, AMF121454, 'KIL' 60; **P**, *Yaoxiangnathus wrighti* Savage, 1990; Pa element, AMF121455, 'KIL' 48. **Q**, *Pseudooneotodus mitratus* (Moskalenko, 1973); AMF121456, 'KIL' 173.1; scale bars 100 µm.

Discussion

Bergström and Sweet (1966) reconstructed the species as having a seximembrate apparatus, and this concept has been accepted since then by most conodont workers. The holotype of the species is a ramiform specimen referred to as the Sb element (previously the form species *Loxognathus grandis* Ethington, 1959). The Sa position is taken by the form species *Trichonodella insolita* Ethington, 1959, the Sc element is the form species *Eoligonodina magna* Ethington, 1959 (see Bergström and Sweet 1966; and Sweet 1988), while the form species *Prioniodina araea* Webers, 1966 and *Ligonodina tortilis* Sweet and Bergström 1962 were assigned to the Pa and Pb positions respectively. As admitted by Bergström and Sweet (1966: 364), *P. grandis* and *P. aculeatus* Hadding, 1913, the likely direct ancestor of the former, are "similar in overall shape and in most morphologic features." These authors suggested that the geniculate M element of *P. grandis*, as the most characteristic form, could be differentiated from the same element of *P. aculeatus* by having a large, subtriangular base with essentially straight basal margin, and by having denticles on the anterior margin closely appressed to it rather than developed into an anterior process. Lindström (*in* Ziegler 1981) suggested distinguishing these two species by the denticles along the anterior margin of the M element reaching higher towards the tip of the cusp, and by the greater number (about 6 or more) of denticles between the cusp and the biggest denticle on the posterior process of the S elements in *P. grandis*. However, the present central NSW material exhibit a rather centrally, downwardly arched basal margin, and typically more than six smaller denticles between the cusp and the largest denticles on the posterior process. Specimens referred as *P. grandis* showing similar arched basal margin of the M element were also recorded previously from North America (Webers 1966).

Genus TAOQUPOGNATHUS An *in* An et al., 1985

Type species

Taoqupognathus blandus An *in* An et al., 1985.

Taoqupognathus blandus An *in* An et al., 1985

Fig. 7E-H

Synonymy

1985 *Taoqupognathus blandus* An *in* An et al., p. 104, pl. 2, figs 18, 19; An, 1987, p. 192, pl. 30, fig. 20; An and Zheng, 1990, pl. 7, figs 5, 6, 20; Zhen and Webby, 1995, p. 287, pl. 6, figs 1-13; Zhen et al., 1999, p.94-96, Fig. 14.10-16; Wang and Qi, 2001, pl. 2, fig. 15.

Material

Forty-one specimens (11 M, 3 Sb2, 1 Sc2, 6 Sc3, 16 Sc5, 4 undifferentiated S elements) from limestone blocks 'KIL-A', 'KIL-B', 'KIL-C', 'FT', 'KILN', 'WKILN', and 'EURO'.

Discussion

In the lower part of limestone block KIL-C, *T. philipi* and *T. blandus* co-occur. One specimen, from sample 'KIL' 95.7 (Fig. 7E), shows features transitional between typical Sc5 elements of *T. philipi* and *T. blandus*. Considering its rather prominent posterior bulging, we regard this element as an early representative of the Sc5 element of *T. blandus*. A specimen of the Sb2 element of *T. blandus* is also recovered from a slightly lower level (Fig. 7F). Specimens from the upper part of limestone block 'KIL-C' with more prominent and stronger posterior bulging (Fig. 7G), are identical with those illustrated from the upper Belubula Limestone and Vandon Limestone (Zhen and Webby 1995).

Taoqupognathus philipi Savage, 1990

Fig. 7I, J

Synonymy

Taoqupognathus philipi Savage, 1990, p. 828, fig. 8.1-8.12; Zhen and Webby, 1995, p. 287, pl., 5, figs 7-22; non McCracken, 2000, p. 194, pl. 1, fig. 28.

Taoqupognathus tumidus Trotter and Webby, 1995; Furey-Greig, 1999, p. 312, *partim*, only pl. 4, figs 2, 9.

Material

Twenty-two specimens (5 M1, 8 M2, 1 Sc3, 8 Sc5 elements) from the lower part of the limestone block 'KIL-C', and two doubtful specimens from limestone block 'KIL-B'.

Discussion

Taoqupognathus philipi, the oldest species of the genus, is characterized by having slender, elongated elements, with only weakly developed posterior bulging on the S elements. It has been recorded from the Fossil Hill Limestone of the Cliefden Caves Limestone Group (Savage 1990; Zhen and Webby 1995), and the lower Reedy Creek Limestone (Percival, Morgan and Scott 1999) of central New South Wales. Several Sc5 specimens showing the characteristic features of the species (Fig. 7H, I, J) were recovered from block 'KIL-C'. In comparison with the holotype of *T. philipi* from the Fossil Hill Limestone (Savage 1990: fig. 8.11, 8.12), these specimens exhibit a weaker development of posterior bulging and a gently curved anterior margin. No P elements have been recovered from any of our samples.

So far *Taoqupognathus* has only been recorded from Australia and China (Zhen 2001). McCracken (2000) reported the occurrence of *T. philipi* from the Frobisher Bay and Amadjuak formations of southern Baffin Island. McCracken's identification was based on two specimens, one from each formation, but only one supposed Sc5 element was illustrated (McCracken 2000: pl. 1, fig. 28). In our opinion, this specimen cannot even be assigned with any certainty to the Panderodontidae. It lacks any distinctive characters of *Taoqupognathus*, except for a superficially similar outline, especially the tip of the cusp. Similar shape outlines are also seen in some Early Ordovician taxa, like *Macerodus* Fåhraeus and Nowlan, 1978 (also see Ji and Barnes, 1994).

Taoqupognathus tumidus Trotter and Webby, 1995

Fig. 7K

Synonymy

Drepanodus? *altipes*? Palmieri, 1978, pl. 2, figs 24, 25.

gen. unident. Pickett, 1978, fig. 4.

Belodina cf. *B. blandus* (An); Duan, 1990, p. 31, pl. 5, fig.7.

Taoqupognathus tumidus Trotter and Webby, 1995, p. 487, pl. 7, figs 10-24; Zhen et al., 1999,

Figure 7. SEM photographs of Late Ordovician conodonts from allochthonous limestones within the Barnby Hills Shale. **A,** *Pseudobelodina* sp. Zhen et al., 1999; AMF121457, 'WKILN-C'. **B-D,** *Protopanderodus liripipus* Kennedy, Barnes and Uyeno, 1979; B, symmetrical element, AMF121458, 'KIL' 119.5; C, asymmetrical element, AMF121459, 'KIL' 173.1; D, weakly asymmetrical element, AMF121460, 'KIL' 173.1. **E-H,** *Taoqupognathus blandus* An *in* An et al., 1985; E, ?Sc5 element, AMF121765, 'KIL' 95.7; F, Sb2 element, AMF121766, 'KIL' 91; G, Sc5 element, AMF121463, 'WKILN-C'; H, Sc5 element, AMF121464, 'WKILN-B'. **I, J,** *Taoqupognathus philipi* Savage, 1990; Sc5 element, I, AMF121465, 'KIL' 97.5, J, AMF121466, 'KIL' 100.1. **K,** *Taoqupognathus tumidus* Trotter and Webby, 1995; P element, AMF121467, 'KIL' 38. **L-N,** *Webbygnathus munusculum* Pickett and Furey-Greig, 2000; Pa element, AMF121468, 'KIL' 95. **O, P,** *Yaoxianognathus* sp.; O, Pa element, AMF121470, 'KIL '100.1; P, Pb element, AMF121469, 'KIL' 48; **Q, R,** *Yaoxianognathus? tunguskaensis* (Moskalenko, 1973); Q, Sc element, AMF121461, 'KIL' 95; R, Sd element, AMF121462, 'KIL' 89; scale bars 100 µm.

p. 96, fig. 14.1-14.9; Percival, 1999, fig. 3.1, 3.2, 3.5; Packham et al., 1999, fig. 3.14-3.16; Furey-Greig, 1999, p. 312, *partim* only, pl. 4, figs 1, 3-8.

Taoqupognathus ani Wang and Zhou, 1998, p. 190, pl. 3, fig. 4.

Material

A single P element from the lower part of limestone block 'KIL-B'.

Discussion

This species seems much wider in distribution than the other two stratigraphically older species in eastern

Australia and China. After the submission of a review paper on the genus (Zhen 2001), YYZ had the opportunity to examine the late Professor An's conodont collection from the Taoqupo section near Yaoxian (An and Zheng 1990: 81-87), housed at the Department of Geology, Beijing University. Four specimens referable to P, Sb1, and Sb2 elements of *T. tumidus* were recognised in the sample TP34Y-5, which was taken about 30 m below the occurrence of *Favisitina* sp. at the top of the Taoqupo Formation.

T. ani Wang and Zhou, 1998 from the Upper Ordovician of the Tarim Basin is a form species based only on a single element, which is identical to the P element of *T. tumidus* from eastern Australia.

Phylum BRACHIOPODA Duméril, 1806
?Subphylum CRANIIFORMEA Popov et al., 1993
?Class CRANIATA Williams et al., 1996
?Order CRANIIDA Waagen, 1885
?Family CRANIIDAE Menke, 1828

unnamed ?craniid
Fig. 8 ff-kk

Material.
Five ventral? valves from 'KIL' section at 53.5, 58, and 59 m.

Discussion.
Classification of these specimens is problematic, as – if in fact they are craniids – they are atypical of this group. The valves are assumed to be ventral in position because of the apparent and consistent presence of a pedicle foramen. If so, this would be the first recognition of this feature in the remarkably long history of the craniids, which have displayed morphological conservatism from their appearance in the Ordovician to the present day. Most representatives of the group (including all living forms) are cemented to the substrate by their ventral valves. Two genera (*Orthisocrania* and *Pseudocrania*) interpreted as free-living are known from the Ordovician, but neither possesses a foramen.

The specimens from the Eurimbla block are subconical in profile, and circular to ovate in outline (although incompletely preserved, so that orientation is uncertain). There is a suggestion that growth may have been mixoperipheral, as there appears to be a straight hingeline in the largest valve (Fig. 8 kk). Ornament comprises coarse radial costae of irregular size; that extending from the pedicle foramen is often (but not always) the most pronounced. Internal musculature is not preserved, and the dorsal valve is unknown. For these reasons, the taxon is not formally named. No other craniids have been described from Lachlan Orogen strata of Late Ordovician age. However, their recognition may have been impeded by the fact that fragmentary remains would appear indistinguishable from other silicified debris retrieved from acid dissolution of limestones; it is only when the valves are reasonably intact that their affinities can be determined.

Subphylum RHYNCHONELLIFORMEA Williams et al., 1996
Class STROPHOMENATA Williams et al., 1996
Order STROPHOMENIDA Opik, 1934
Superfamily PLECTAMBONITOIDEA Jones, 1928
Family LEPTELLINIDAE Ulrich and Cooper, 1936
Subfamily LEPTELLININAE Ulrich and Cooper, 1936
Genus MABELLA Klenina *in* Klenina, Nikitin and Popov, 1984

Mabella halis (Percival, 1991)
Fig. 8 o-t

Wiradjuriella halis Percival, 1991, p. 138-141, fig. 12: 1-38; Percival 1992, fig. 4: 10, fig. 5: 37-38.
Mabella halis (Percival, 1991), Cocks and Rong Jia-yu 2000, p. 322-323, fig. 208: 2f-i.

Material.
Six valves figured from 'KIL' section, plus several hundred additional specimens.

Discussion.
These specimens conform in all regards to the description given by Percival (1991). *Mabella* sp. is also known from younger (late Eastonian) strata at Gunningbland in the Junee-Narromine Volcanic Belt, where it was first described as aff. *Leptellina* sp. by Percival (1979) and subsequently illustrated as *Wiradjuriella* sp. in Percival (1992: fig. 6, 31). A potential ancestor of *M. halis* may be *Leptellina*? sp. from the Wahringa Limestone Member of the Fairbridge Volcanics, which is exposed at Bakers Swamp, less than 15 kms north of Eurimbla; this occurrence is of earliest Gisbornian (basal Late Ordovician) age (Percival et al. 2001). Other species referred to *Mabella* (according to Percival et al. 2001: 228) include *M. solida* (Nikitin and Popov, 1984) and *M. namasensis* (Klenina, 1984), as well as *M. conferta* (Popov, 1985); all three are from Kazakhstan.

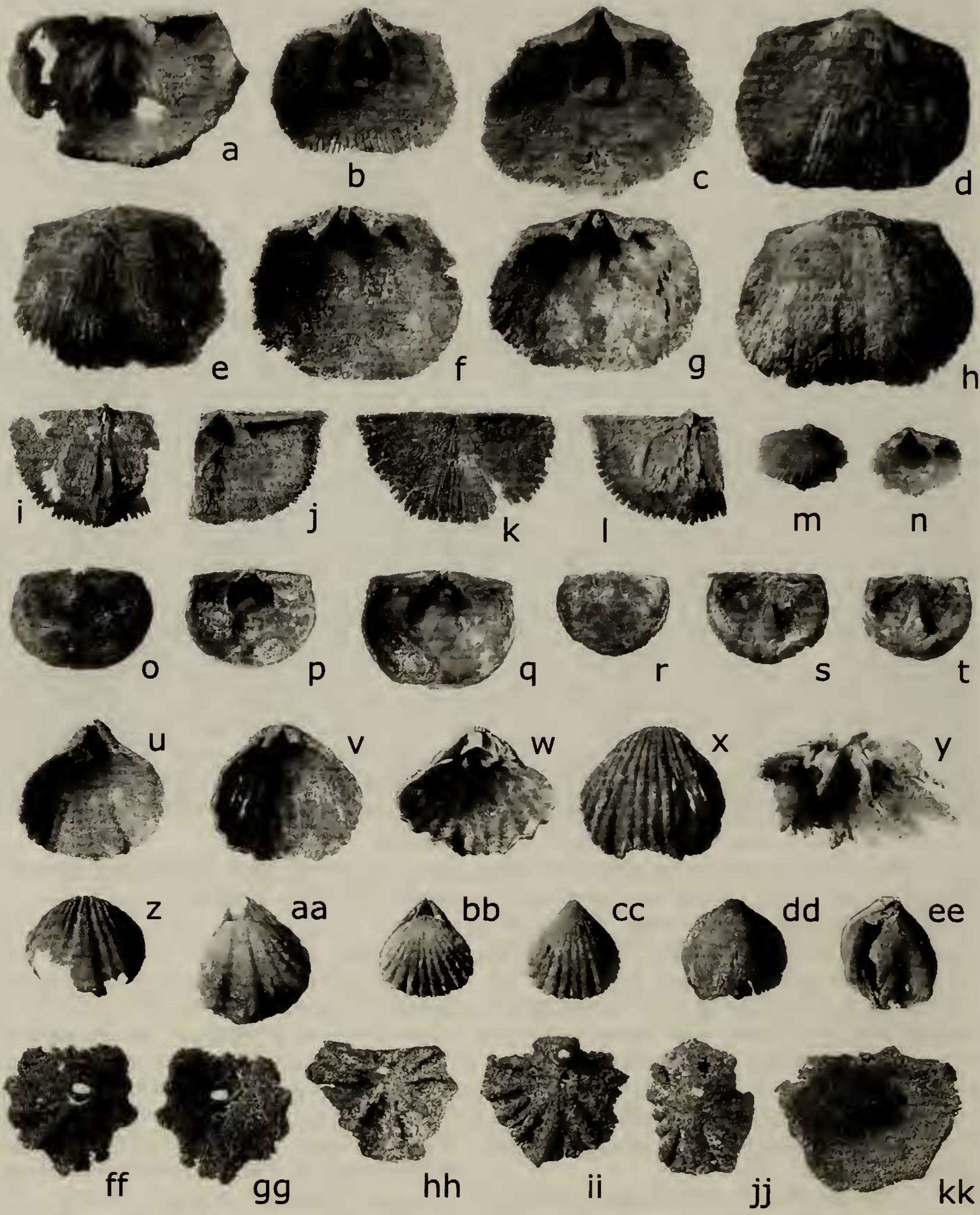

Figure 8. Silicified brachiopods of Late Ordovician age from allochthonous limestone block ‘KIL’ within the Barnby Hills Shale; all photographs taken by digital camera of unwhitened specimens. All specimens from horizon ‘KIL’ 53.5 unless otherwise stated. Magnifications all x2 unless otherwise stated. **a**, *Chaganella speciosa* (Percival, 1991), ventral valve interior, MMF36922. **b-h**, *Doleroides mixticius* Percival, 1991; b, ventral valve interior, MMF36923; c, ventral valve interior, MMF36924; d, ventral valve exterior, MMF36925; e, ventral valve exterior, MMF36926; f, dorsal valve interior, MMF36927; g, dorsal valve interior, MMF36928; h, dorsal valve exterior, MMF36929. **i-l**, *Sowerbyella billabongensis* Percival, 1991; i, dorsal valve interior, MMF36930; j, ventral valve interior, MMF36931; k, dorsal valve exterior, MMF 36932; l., dorsal valve interior, MMF36933. **m**, **n**, *Skenidioides quondongensis*? Percival, 1991; exterior and interior views

(Figure 8 continued) (both x3) of incomplete ventral valve, MMF36934, from 'KIL' 59. **o-t**, *Mabella halis* (Percival, 1991); o, ventral valve exterior, MMF36935; p, ventral valve interior, MMF36936; q, ventral valve interior, MMF36937; r, dorsal valve exterior, MMF36938; s, dorsal valve interior, MMF36939; t, dorsal valve interior, MMF36940. **u-y**, *Rhynchotrema oepiki* Percival, 1991; u, ventral valve interior, MMF36941; v, x, dorsal valve interior and exterior, MMF36942; w, dorsal valve interior with interlocked posterior fragment of ventral valve; y, enlargement (x3) of posterior fragment of dorsal valve interior, showing crura, MMF36943. **z, aa**, *Australispira disticha* Percival, 1991; z, incomplete dorsal valve exterior, MMF36944; aa, dorsal view (x3) of juvenile conjoined valves, MMF36945. **bb, cc**, *Zygospira carinata* Percival, 1991; dorsal and ventral views of conjoined valves, MMF36946, x4. **dd, ee**, *Protozyga definitiva* Percival, 1991; ventral valve exterior, and oblique lateral view of conjoined valves, dorsal valve to right, MMF36947, x4. **ff-kk**, unnamed craniid?, all x3; ff, gg, exterior and interior views of presumed ventral valve, MMF36948, from 'KIL' 58; hh, exterior view of presumed ventral valve, MMF36949, from 'KIL' 59; ii, exterior view of presumed ventral valve, MMF36950, from 'KIL' 58; jj, exterior view of presumed ventral valve, MMF36951, from 'KIL' 59; kk, interior view of ?ventral valve, MMF36952.

Family HESPEROMENIDAE Cooper, 1956
Genus CHAGANELLA Nikitin, 1974

Chaganella speciosa (Percival, 1991)
Fig. 8a

Tylambonites speciosa Percival 1991, p. 143-144, fig. 13: 14-35; Percival 1992, fig 4: 11-3, fig. 5: 46-47.
Chaganella speciosa (Percival, 1991) Cocks and Rong Jia-yu 2000, p. 339, fig. 222: 2e-h.

Material.
One specimen, a fragmentary ventral valve from 'KIL' section at 53.5 m.

Discussion.
Percival (1991: 143) noted substantial similarities between *Tylambonites* and *Chaganella*, but differentiated these genera on lack of a pedicle callist in *Chaganella* and chilidial plates being partially fused in the latter rather than discrete as in *Tylambonites*. Such distinctions are now regarded as of specific rather than generic significance.

Class RHYNCHONELLATA Williams et al., 1996
Order ORTHIDA Schuchert and Cooper, 1932
Superfamily PLECTORTHOIDEA Schuchert and LeVene, 1929
Family PLECTORTHIDAE Schuchert and LeVene, 1929
Genus DOLEROIDES Cooper, 1930

Doleroides mixticius Percival, 1991
Fig. 8b-h

Doleroides mixticius Percival 1991, p. 127, 129, fig. 8: 17-39; Percival 1992, fig. 5: 19-21.

Material.
Abundant valves from 'KIL' section at 53.5 m.

Discussion.
The characteristic *Mimella*-like appearance of the ventral muscle field, previously noted by Percival (1991) when establishing the species, is well in evidence in some specimens (eg, Fig. 8b) from the Eurimbla allochthonous block, where *D. mixticius* is one of the most dominant forms. In all other morphological aspects, this species conforms to the generic concept of *Doleroides* as summarised in the recently revised brachiopod Treatise (Williams and Harper 2000: 759).

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